

DEGRADATION OF PHENOL BY CATALYTIC OZONATION

P. YOGESWARY¹, MOHD RASHID MOHD YUSOF², NOR AISHAH SAIDINA AMIN

Abstract. The performance of a metal-based zeolite catalyst (Fe-ZB) was investigated by ozonation process under different experimental variables such as the ozone flow rate, mass and metal weight percent impregnated in the catalyst, temperature, initial pH, concentration and the volume of phenol solution to be treated. The degradation of phenol in the study was determined using HPLC method. In addition, the degree of degradation was also determined indirectly through Chemical Oxygen Demand (COD) and Total Organic Carbon (TOC) of the samples. It was observed that a smaller percentage of metal loading catalyst resulted in a higher degradation of phenol compared to those with higher metal loading catalyst. As expected, the degradation of phenol increases with ozone flow rates and mass of catalyst. Interestingly, the degradation of phenol was significantly high under basic condition where the degradation was almost completed i.e 98.1% at initial phenol solution of pH 11. On the contrary, the degradation of phenol decreases with increasing temperature, concentration and volume of phenol solution.

Key Words: Catalytic ozonation process, Fe-ZB catalyst, operating variables, degradation of phenol, Total Organic Carbon, Chemical Oxygen Demand.

1.0 INTRODUCTION

In many cases, chemical industries use a large quantity of water and thus generating considerable amount of toxic and harmful industrial effluent. Sometimes conventional wastewater treatment method failed to treat persistent organic pollutant effectively. Chemical oxidation with ozone can be used to treat organic pollutants or act as disinfectant agents.

Ozone is a powerful oxidant able to oxidize a great number of organic and inorganic materials. Ozone based technologies research is also being focused on the catalytic ozonation where the presence of catalyst significantly improved the oxidation rate of organic compounds compared to non catalytic ozonation. However, the characteristics of the wastewater such as pH, temperature and concentration of organic pollutant play an important role in organic degradation [1].

To date chemical oxidation with ozone is considered as one of the techniques used in wastewater treatment for the removal of organic pollutants. The use of high oxidation potential like ozonation has recently received much attention in wastewater treatment studies. In some cases, ozone is used in combination with other agents to improve the degradation rate of organic pollutants. This study investigates the degradation of phenol using ozonation on with metal-based zeolite catalyst (Fe-ZB) presence in the treatment.

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2.0 MATERIALS AND METHODS

The influence of different variables such as ozone flow rates, mass and metal weight percent impregnated in the catalyst, temperature pH, concentration and the volume of phenol solution to be treated were investigated on the Fe-ZB catalyst. The purpose of the experiment was to determine the optimum operating conditions of the degradation of phenol by the Fe-ZB catalyst.

Figure 1 presents the experimental set-up of the study. One gram of the powdered calcinated Fe-ZB catalyst was added into a 100ppm of 250mL phenol solutions (BDH chemical Ltd). The experiment was carried out at room temperature with a constant stirring rate of 300rpm. The solution was ozonated (Ozonias Model LAB2B) at the constant flow rate of 0.6L/min for a total period of 120 minutes. Treated samples were collected and analyzed for the degradation of phenol for every 15 minutes of reaction time. The concentration of ozone was controlled by variable output control knob setting of the ozone generator.

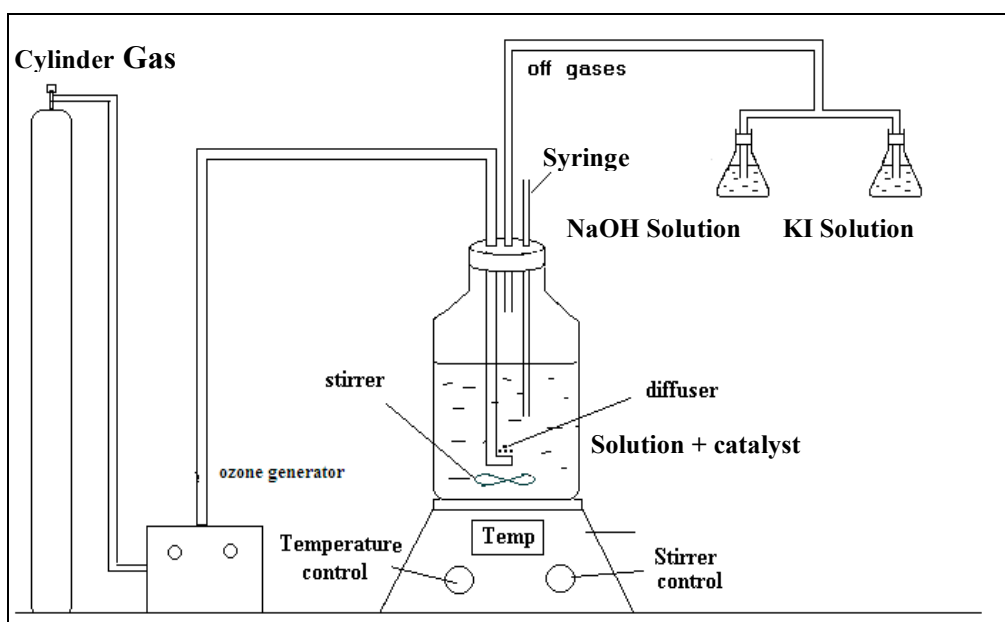


Figure 1 Experimental set up of the study

Table 1 presents the summary of the experimental variables (in column 1) and conditions (in column 2-8) carried out in the experiment. As presented in Table 1, each of the variables in column 1 was prepared and subjected to experimental conditions (in column 2-8). For an example, one gram of 2wt% of metal-based zeolite catalyst was used to treat 100ppm of 250ml phenol solution with ozonation rate of 1L/min. The experiment was repeated with 4 and 6wt% of metal-based zeolite catalyst and subjected to the similar conditions.

Similarly, the effect of ozone flow rate, temperature, pH, amount of catalyst, concentration and volume of phenol on the degradation of phenol was studied following the experimental conditions as presented Table 1.

Table 1 Experimental conditions for the degradation of phenol by metal-based zeolite catalyst

Variables	Experimental condition						
	Temperature	pH	Ozone flow rate L/min	Metal weight %, wt%	Amount of catalyst used, gram	Volume of phenol treated, mL	Concentration of phenol, ppm
Metal weight %, (2, 4 and 6 wt %)	Room temperature	Not adjusted	1.0	-	10	250	100
Ozone flow rates, (0.6,1.5,2.1L/min)	Room temperature	Not adjusted	-	1.0	1.0	250	100
Temperature, (40, 55, 70°C)	-	Not adjusted	1.0	1.0	1.0	250	100
pH, (3, 7, 11)	Room temperature	-	1.0	1.0	1.0	250	100
Amount of catalyst used,(0.5, 3, 5 gram)	Room temperature	Not adjusted	1.0	1.0	-	250	100
Concentration of phenol (200, 400, 800ppm)	Room temperature	Not adjusted	1.0	1.0	1.0	250	-
Volume of phenol treated,(300, 500ml)	Room temperature	Not adjusted	1.0	1.0	1.0	-	100

*The catalytic ozonation of phenol solution using metal-based zeolite catalyst was carried out up to 2 hours

2.1 High Performance Liquid Chromatography

Each of the treated samples of phenol was filtered using 0.45µm pore size nylon syringe filter prior to its determination using the high performance liquid chromatography (HPLC) with wavelength of 254nm UV adsorbance. The HPLC was equipped with an auto sampler (Waters 717 plus Auto sampler) and UV detector (Water 486 Tunable Absorbance Detector) and a reverse phase column (300 mm length, 3.9 mm inner diameter and 5µm particle size). A mixture of 40% acetonitrile (Fisher) and 60% of distilled water was used as the optimal mobile phase for phenol. 5µl volume of phenol was injected with a flow rate of 1 mL/min. The percentage of degradation of phenol in the samples was calculated based on the peak area of the initial and the treated phenol solution as the following,

$$\text{Percentage of Degradation, \%P} = [(P_i - P_t) / P_i] \times 100 \quad (1)$$

Where, P_i = Peak area of initial phenol solution and P_t = Peak area of treated phenol solution

2.2 Chemical Oxygen Demand

The degradation of phenol in the experiment was also measured indirectly by determining the Chemical Oxygen Demand (COD) of the initial and the treated phenol solution. A 2mL of the sample was pipette into a COD vial and placed on heated 150°C COD reactor for two hours. Then, the sample was allowed to cool to 120°C or less for approximately 20 minutes before it was determined calorimetrically at 420nm (HACH,). The percentage COD removal in the sample was determined using the following equation,

$$\% \text{COD removal} = [(\text{COD}_i - \text{COD}_t) / \text{COD}_i] \times 100 \quad (2)$$

Where, COD_i is the initial chemical oxygen demand of phenol solution and COD_t is the final chemical oxygen demand of treated phenol solution.

2.3 Total Organic Carbon

The determination of Total Organic Carbon (TOC) was performed only on the selected set of experiment in this study. Total organic carbon (TOC) of initial and ozonated samples were determined with TOC analyzer (Ve Shimadzu) with 150 mL/min of gas flow rate and 300kPa of gas pressure. The percent degradation of phenol or reduction of the TOC in the sample was calculated by Equation 3.

$$\%TOC \text{ reduction} = \frac{[(TOC_i - TOC_t)/TOC_i] \times 100}{(3)} \quad (3)$$

Where, TOC_i = the initial total organic carbon of phenol solution and TOC_t = the final total organic carbon of treated phenol solution

A detailed experimental setup and procedure of the study had been described elsewhere [2].

3.0 RESULTS AND DISCUSSION

The influence of selected variables such as ozone gas flow rate, temperature and pH of phenol solution, mass and metal weight percent impregnated in the catalyst, concentration and the volume of phenol to be treated was studied to find the degree on the degradation of phenol. The influence of these variables on the degradation of phenol using Fe-ZB catalyst is presented in following sections.

3.1 Effect of Metal Weight Percent

The performance of Fe-ZB catalyst on the degradation of phenol was studied with one gram of the catalyst impregnated with different Fe weight percent of 2, 4 and 6wt%. The experiment was subjected to 1.0 L/min of ozone flow rate to treat 250mL of 100ppm phenol at room temperature with the total reaction time of 120 minutes. The catalytic ozonation of phenol using different metal weight percent of Fe-ZB catalyst was measured against reaction time and their respective performance on the degradation of phenol, COD and TOC (taken only at the end of the experiment) removal was observed.

Figure 2 presents the degradation of phenol with different Fe weight percent, which shows that there was no significant different was observed in degradation with increase in metal weight percent. As expected, the degradation of phenol was increased with increase in the reaction time.

As illustrated in Figure 2, the degradation of phenol was 58.1% with 2 percent of metal weight and remained or slightly improved to 58.1 and 60.4% for 4wt% and 6wt%, respectively for 60 minutes of reaction time. The degradation of phenol was further increased to 67.9, 71.9 and 74.2% for 2, 4, 6 wt% of metal weight percent after 120 minutes of ozonation time. However, there was no marked difference at a higher ferum loading in ZB catalyst on the degradation of phenol. The degradation rate of phenol with different metal weight percent was 0.47 0.46 and 0.43 per minute for 2, 4 and 6 wt% of ferum weight percent, respectively.

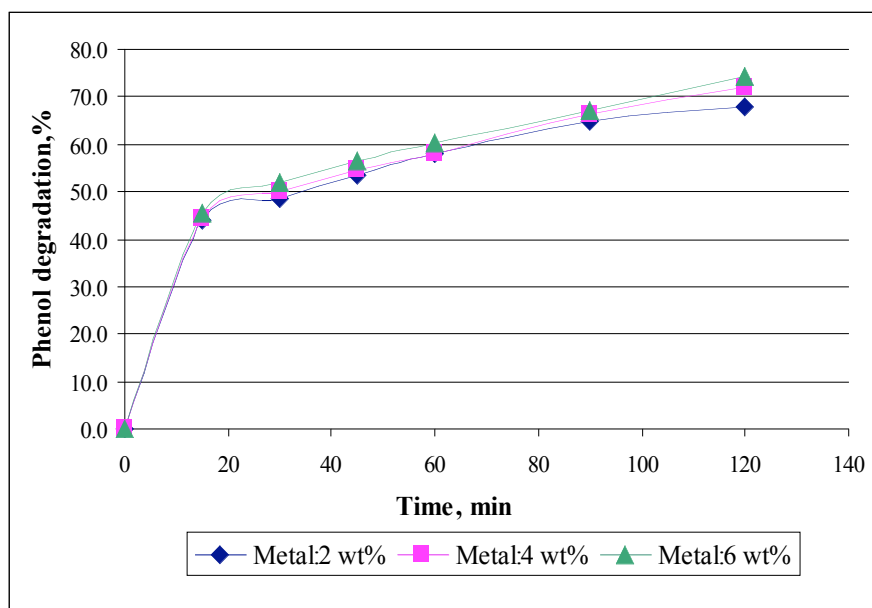


Figure 2 Degradation of phenol with different metal weight percent against reaction time.

Einaga and Futamura [3] have reported that, there was no significant difference on the degradation rate of benzene with increase the Mn loading from 5 to 20 wt% on $\text{MnO}_2/\text{Al}_2\text{O}_3$ catalyst. They found that the benzene degradation rate was similar i.e 1.38×10^{-5} , 1.40×10^{-5} and 1.13×10^{-5} for 5, 10 and 20 wt% of Mn loading, respectively. Increasing metal loading seems does not influence on the degradation rate of pollutant similarly observed in this study.

Ma and Graham [4] showed that, the highest removal of atrazine appeared to occur at the lowest Mn concentration in catalyst where in their study, further increase on Mn concentration did not cause any increase in the degradation of atrazine.

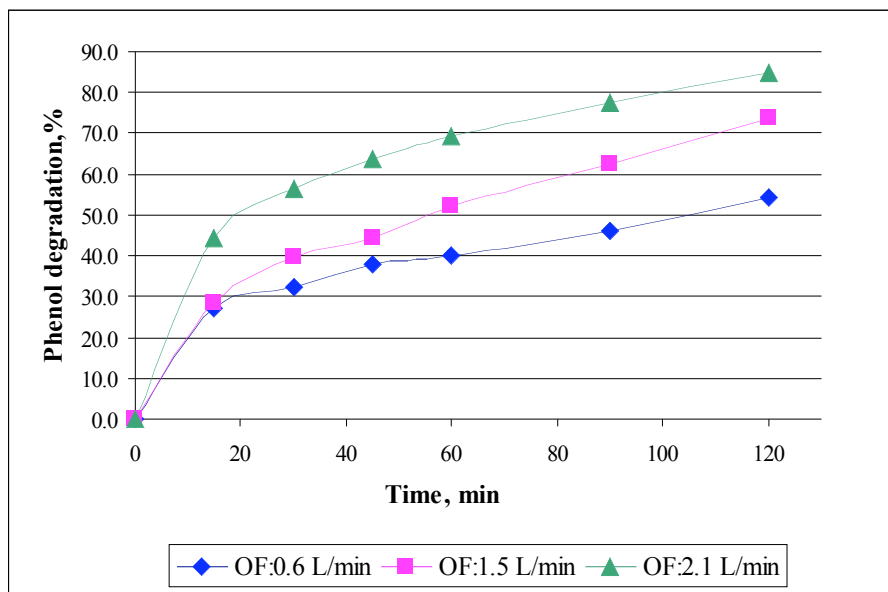
An increased in metal loading catalyst should cause an increased in catalytic ozonation. On the contrary, it was observed that a smaller percentage of metal loading catalyst showed a higher degradation compared to those with higher metal loading catalyst. It seemed that only a very small percentage of metal is required to obtain a substantial degradation whereby a small amount of metal loading catalyst is warrant to initiate any radical chain reaction [5]. However, it is anticipated that the increased in percentage of metal on the based catalyst would require a greater consumption of ozone to show any significant effect.

A similar trend on the degradation of phenol was observed based on the COD and TOC removal where the percentage of COD removal was slightly increased with time i.e 44, 46 and 53% for 2, 4 and 6wt%, respectively after 120 minutes of reaction time. As for the TOC, this was 17.7, 20.8 and 22.5% for 2, 4 and 6 wt%, respectively.

3.2 Effect of Ozone Gas Flow Rates

Figure 3 shows the degradation of the phenol where the degradation of phenol was 54.12% after 120 minutes of reaction time for 0.6L/min, while the same amount of phenol was degraded (51.9%) in 60 minutes for 1.5 L/min of ozone flow rate. Approximately a similar percentage of phenol was degraded (56.4%) in less than 30 minutes for 2.1L/min of ozone flowrate. The degradation of phenol increased from 73.6% to 84.8% as ozone flow rate was increased from 1.5 to 2.1L/min after 120 minutes of reaction time. This indicates that, a higher percentage of phenol degradation was observed at a higher ozone flowrate. A similar reason whereby the increases in the ozone flow rate causes the free OH radicals to

form when ozone decomposed in the solution having the greatest oxidizing potential that increased the degradation rate of organic matter.



Note: OF=Ozone flow rate

Figure 3 The effect of ozone flow rates against reaction time

Figure 3 also presents the graphical presentation of the degradation rate of phenol against ozone flow rate, which clearly shows that the degradation rate of phenol increases with ozone flow rates. The degradation rate was 0.36, 0.53 and 0.57 per minute for ozone flow rate of 0.6, 1.5 and 2.1 L/min, respectively. Similarly, the percentage of COD removal was increased with ozone flow rate i.e 42, 49 and 56% for 0.6, 1.5 and 2.1L/min, respectively after 120 minutes of reaction time.

Figure 4 is a series of HPLC chromatographs for phenol solution taken at various reaction times with the ozone flow rate of 2.1L/min, which clearly shows the gradual disappearance of phenol peak with reaction time. The HPLC spectrum also shows the presence of other unidentified peaks, which indicates the formation of by-products resulting from the degradation of phenol. The degradation of these by-products was also increasing (decrease in the peak area) with time, which concur that the reaction time is of the most important parameter in ozonation process. A similar pattern of observation was obtained with 0.6 and 1.5L/min of ozone flow rate.

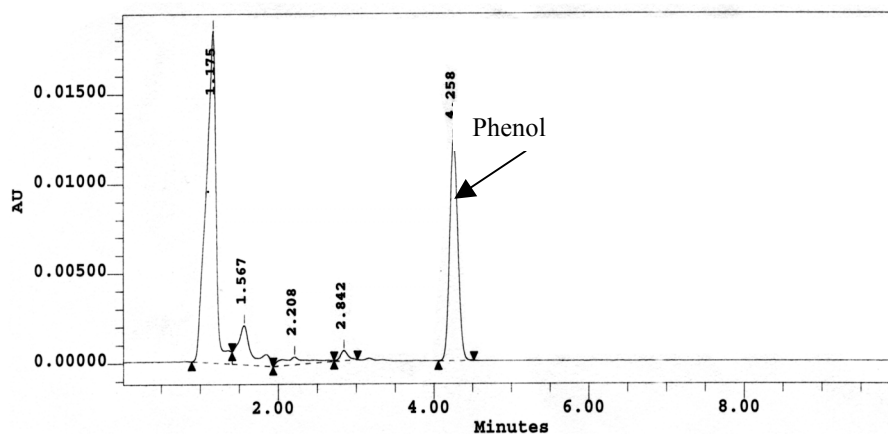
Table 2 shows the effects of ozone flow rates on the TOC removal of pollutant at the end of the experiment which shows the TOC removal was slightly increases with ozone flow rate. The percentage of TOC removal was 11.7, 13.0 and 18.5% for 0.6, 1.5 and 2.1L/min, respectively. As discussed in previous section, the percentage removal of TOC in the study seems lower than the percentage of degradation of phenol as TOC represents the total degradation of intermediate products (due to degradation of phenol) as well as the phenolic solution itself.

Table 2 TOC removal with different ozone gas flow rates

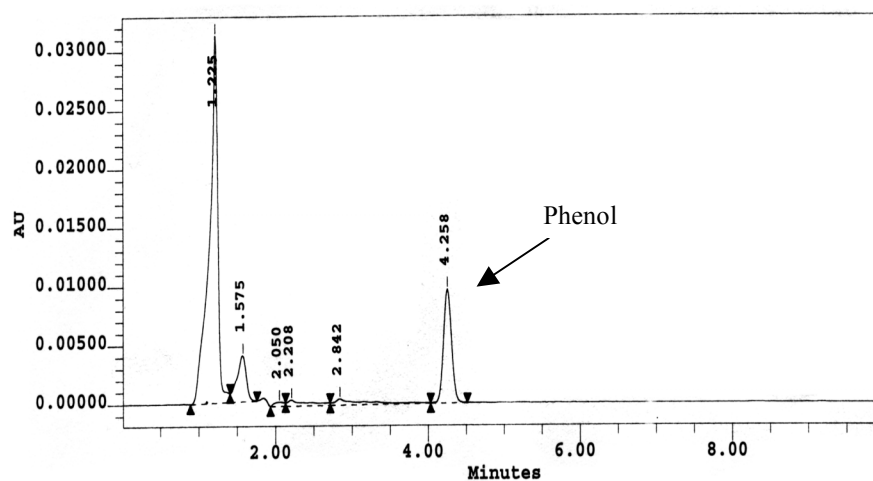
Ozone flow rate	Initial TOC, ppm	Final TOC, ppm	TOC removal, %
0.6	135.1	90.0	33.4
1.5		88.7	34.3
2.1		83.1	38.5

Note: reaction time=120 minutes

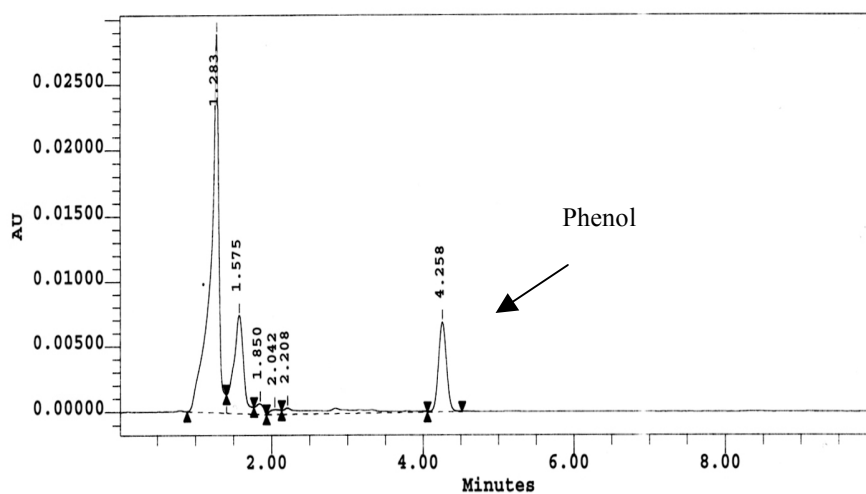
a) 15 min



b) 30 min



c) 45 min



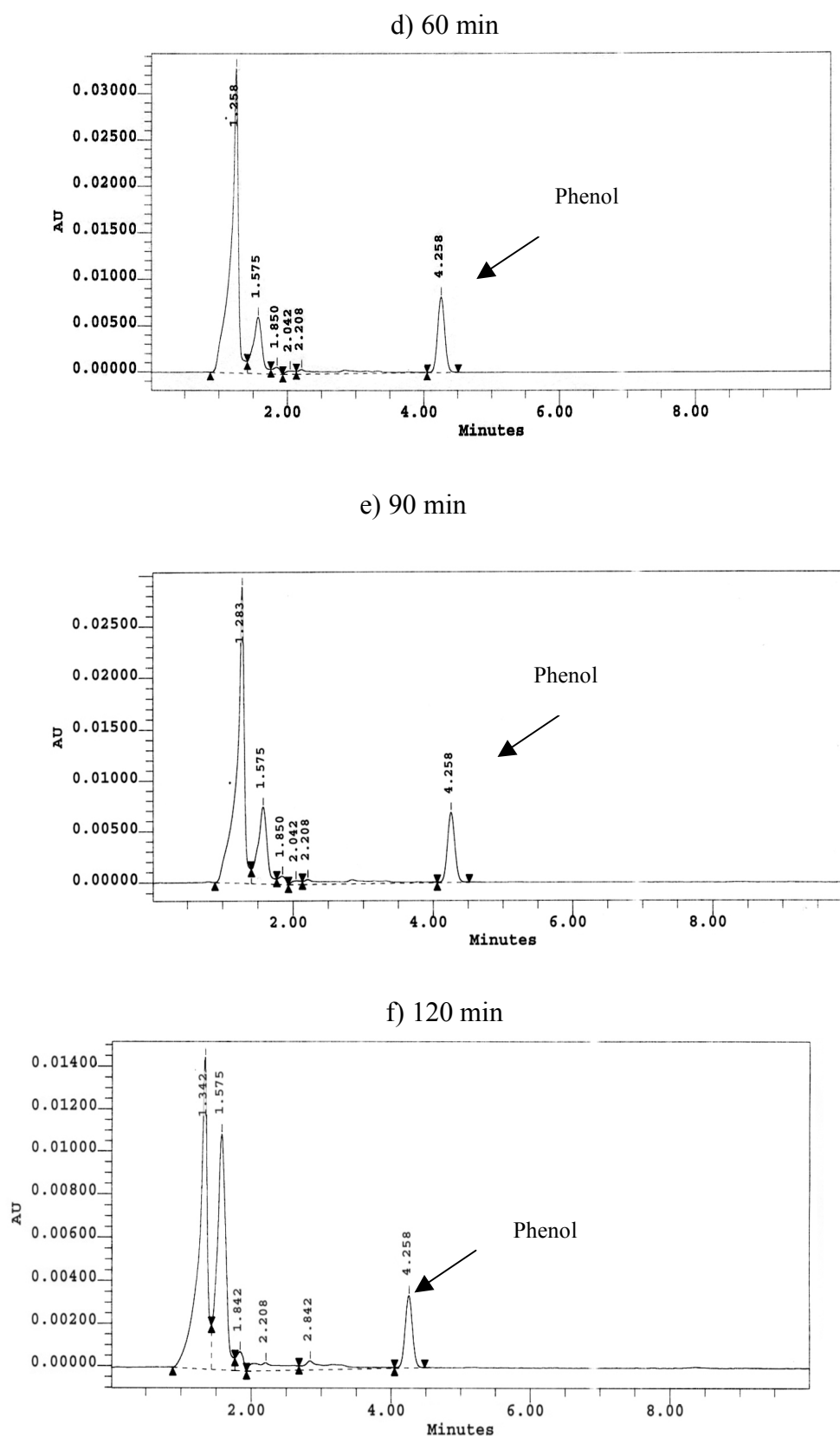


Figure 4 HPLC spectrum of phenol degradation under 2.1 L/min

3.3 Effect of Phenol Concentration

Figure 5 shows that the effect of degradation of phenol with different phenol concentrations against reaction time with constant ozone flow rate. It shows approximately 35.0% phenol degraded with the first 15 minutes and gradually increases to 62.8% after 120 minutes of reaction time for 200ppm of phenol. The degradation of phenol was 24.5% within 15 minutes of ozonation time and for a longer reaction time of 120 minutes, at least 46.1% of phenol is degraded for 400ppm phenol. Finally, for 800ppm of phenol, the degradation was only 14.9% in the first 15 minutes and gradually increases to 30.7% after 120 minutes of reaction time. The percentage of COD removal was 75%, 64% and 53% for 200, 400 and 800ppm of phenol, respectively.

It is theorized that the most of the ozone generated was used for destroying phenol and its intermediates causing insufficient ozone to degrade the remaining phenol quickly. Nevertheless, varying other operating parameters such as increase in ozone flow rate and reaction time could increase the degradation and COD removal of phenol as can be observed in previous experiments.

Figure 5 also shows that the degradation rate of phenol at different concentration where the degradation rate was decreased with concentration of phenol. The degradation rate was 0.43 per minute for 200ppm phenol. When the concentration of phenol increased from 200 and 400ppm, the degradation rate of phenol was 0.32 per minute and finally the degradation rate was decreased to 0.21 per minute for 800ppm of phenol. The results clearly indicate that the degradation rate was decreased with increase in phenol concentration.

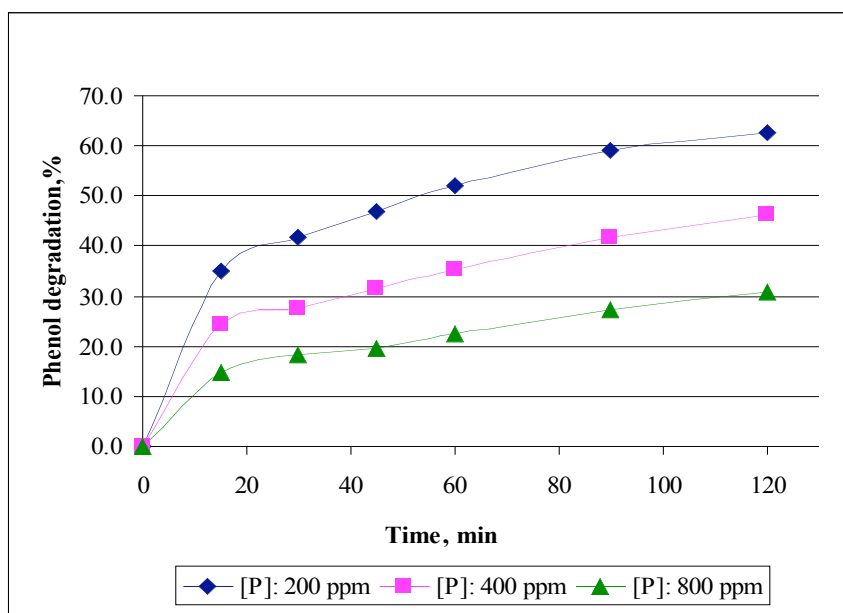


Figure 5 The effect of different concentration of phenol against the reaction time

Similar results was observed by Anaizy *et al.*, [6], where approximately 90% oxidation of phenol was achieved in 20 min and complete oxidation was achieved in less than 30 minutes for 40ppm of phenol. The oxidation decreased significantly when the initial phenol concentration was increased to approximately 500ppm, only 14% was oxidized over a 30 minutes of reaction time. In addition the authors also observed that the reduction rate of COD was much slower than phenol oxidation rate.

3.4 Effect of Initial pH

The pH of the aqueous solution is one of the most important environmental parameters significantly influences in the degradation of pollutant. The pH plays an important role in the formation of OH and, thus expected to enhance the pollutant oxidation rate. The oxidation by ozonation process involving hydroxyl radical has shown their potential to destroy organic compounds in wastewater. The main interesting characteristic of the hydroxyl radicals is its oxidation potential that leads to an indirect attack on organic compounds, which is faster than a direct attack by molecular ozone.

Since pH is a key condition for ozone stability in aqueous solution, it is important to examine the influence of pH in catalytic ozonation of phenol solution. Therefore, it is necessary to adjust the initial pH of the solution in order to determining its role in the degradation of organic pollutants.

The effect of initial pH (selected pH 3, 7 and 11) of 100ppm phenol solution on the degradation of phenol was tested over a period of 120 minutes reaction time. The initial pH of the solution was adjusted using either sodium hydroxide or acid sulfuric and the solution was subjected to 1.0 L/min of ozone flow rate.

Figure 6 illustrates the degradation and COD removal of phenol against reaction time with different initial pH, which shows the degradation of phenol was higher in a basic condition by two orders of magnitudes compared to the neutral and acidic conditions. The degradation of phenol increased significantly from 54.8 (at pH 7.0) to 98.1% (at pH 11) after 120 minutes of reaction time. In addition, approximately 88.2% of phenol was degraded within the first 15 minutes of the reaction time where almost complete degradation of phenol was observed in the basic condition. The rate of decomposition of ozone increases at high pH thus producing a higher concentration of hydroxyl radical that significantly help to the degradation of phenol [7]. The degree of degradation of phenol was similar in the case of acidic and neutral conditions.

Esplugas *et al.*, [8] found that, the ozonation process of phenol gives a better efficiency at basic pH rather than neutral and acidic conditions and the increased in the formation of the hydroxyl radical during ozonation at a higher pH contribute to this effect. In addition, Morkini *et al.*, [9] have shown that, the degradation of benzoic was 54.2%, 84.8% and 98.7% for acidic, neutral and basic condition, respectively; increasing from acid to base. The authors conclude that the presence of the hydroxyl radical during ozonation increase the efficiency of the degradation and a similar explanation can be given in this study.

Figure 7 shows that the HPLC spectrum for the phenol samples taken at the end of ozonation time (120 minutes) with different pH. It can be seen that, the peak corresponding to phenol almost fully disappears with pH 11, and the intermediate compounds are further oxidized, as indicated by the reduction in the peak areas at pH 3 and 7.

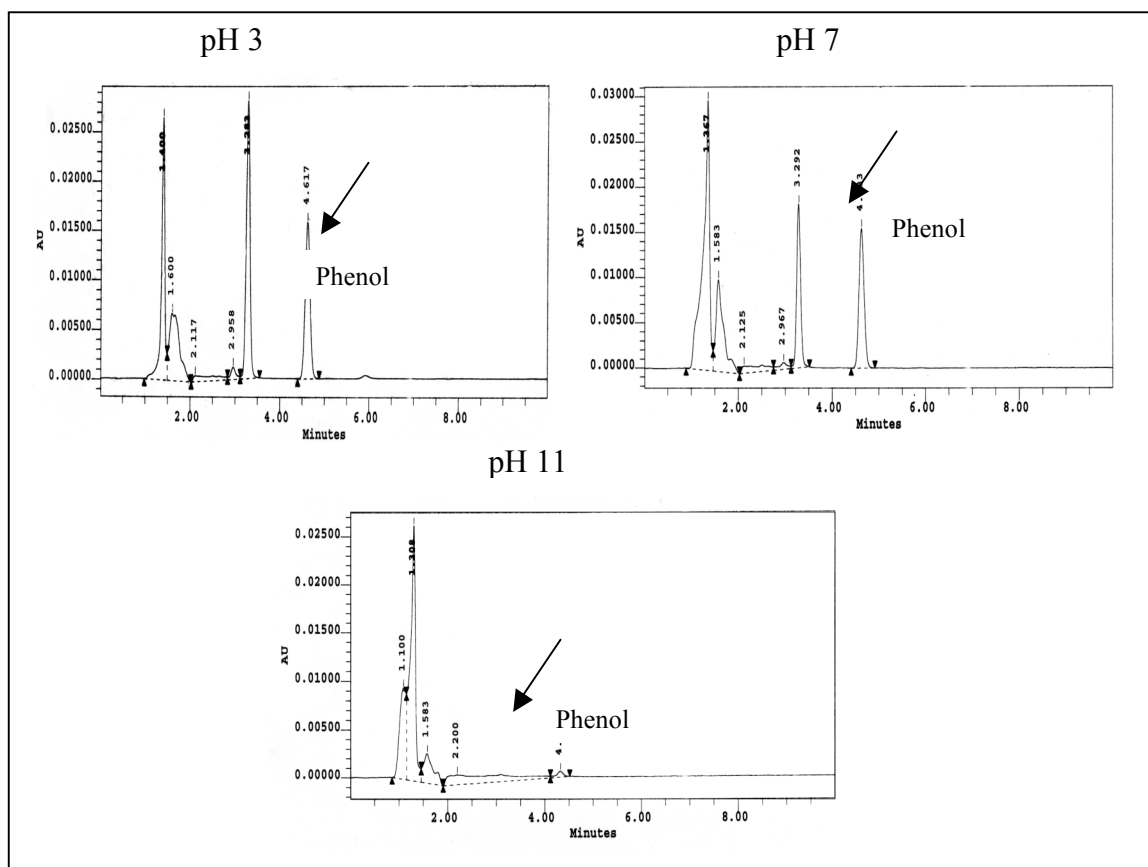


Figure 6 HPLC spectrum at different initial pH of solution

A similar pattern on the removal of COD was observed where 26% and 52% of COD was removed in 30 and 120 minutes with pH 3, respectively. The removal was slightly increased to 34% and 53% after 30 and 120 minutes of reaction time, respectively when the pH increases to 7. Similarly, a higher removal was achieved i.e. 55% and 79% after 30 and 120 minutes, respectively when the pH was further increased to pH 11. A high percentage of COD removal was observed due to the decomposition of ozone at a faster rate which produces more OH radical at basic pH compared to other pH condition. The OH radical causes an increase in the rate of the oxidation process [5, 9 and 10].

Freshour [7] studied the degradation of 100ppm oxalic acid at initial pH of 11.5 and 2.8, which shows that 67% oxalic acid was degraded within 70 min at the higher pH and 45% at the lower pH as observed in this study. The authors reported that the ozone does not decompose rapidly in the acidic environment, and a direct attack of merely ozone on the compound predominates. However, at basic pH, the decomposition of ozone enhanced the forming of OH radicals in water, causing on indirect attack mechanism on organic pollutant. This enhances the degradation of organic pollutant in the solution.

Figure 7 illustrates the degradation rate of phenol under different pH values where the degradation rate of phenol at pH 11 was 1.2 higher than those hydroxyl ion to react with holes to form hydroxyl radicals, subsequently enhancing the efficiency of the ozonation process.

In addition, the concentration of OH radicals increases with pH of the solution, which have a high oxidation potential of 2.80V compared with ozone alone, which has an

oxidation potential 2.07V. Thus, it is expected that the decomposition reaction is faster in basic conditions where these OH radicals are readily available [12].

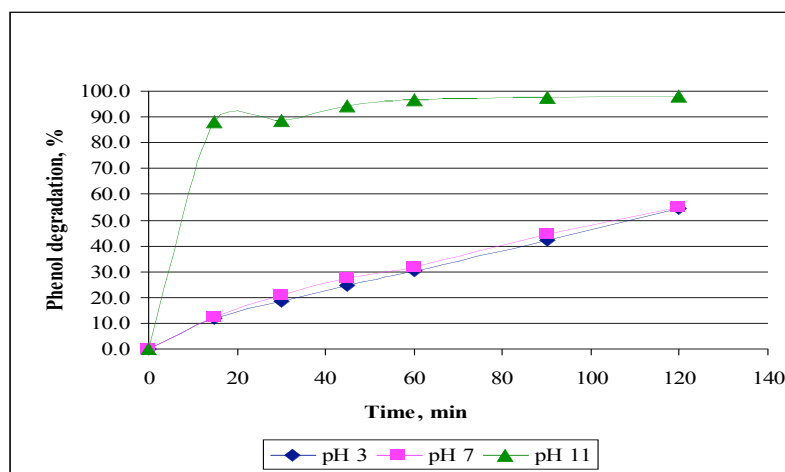


Figure 7 Effect of initial pH of phenol against reaction time

3.5 Effect of Mass of Catalyst

Table 3 presents the results on the effect of mass of Fe-ZB against reaction time, which generally shows the value of phenol degradation, was increased with increase ozonation time and mass of catalyst. The degradation of phenol with 0.5g of Fe-ZB catalyst was 48.0% in 90 minutes of reaction time. Approximately the same amount of phenol was degraded (47.2%) in the solution with 3g of Fe-ZB catalyst, which took 60 minutes of reaction time.

Table 3 Effect of mass of 1wt% Fe-ZB catalyst in the ozonation process

Time, min	Mass of catalyst = 0.5 gram			Mass of catalyst = 3 gram			Mass of catalyst = 5 gram		
	%P	COD, mg/l	%COD	%P	COD, mg/l	%COD	%P	COD, mg/l	%COD
15	17.0	-	-	28.9	-	-	39.5	-	-
30	24.6	190	36	38.1	115	61	42.7	110	63
45	31.0	-	-	42.5	-	-	48.2	-	-
60	37.2	180	38	47.2	110	63	52.3	105	64
90	48.0	-	-	54.4	-	-	61.8	-	-
120	60.0	150	49	61.2	85	71	65.2	35	88

Note: %P: Degradation of phenol; Initial COD=295 mg/L, ozone flow rate=1.0L/min

In comparison, catalytic ozonation in the presence of 5 gram of Fe-ZB catalyst required only 45 minutes of reaction time to achieve a similar level of degradation. This indicates that the degradation was slightly faster in the presence of 5 gram of Fe-ZB catalyst compared to others. Similarly, the same effect in the process oxalic acid oxidation in the TiO_2/O_3 system was observed by Beltran *et al.*[13]. The author reported that an increased in catalyst mass in the process oxalic acid ozonation on TiO_2 resulted increased in the efficiency of the process. In addition, in their study on degradation of phenolic wastewaters over Ni-Oxide found that the oxidation efficiency increases with the amount of catalyst added [14].

A similar trend of COD removal of the solution was observed where the percentage of COD removed was 36, 61 and 63% within 30 minutes and was increased to 88%, 71% and 49% after 120 minutes for 0.5, 3 and 5g of Fe-ZB catalyst, respectively (Table 3).

3.6 Effect of Temperature

The performance of Fe-ZB catalyst (1 gram) on the degradation of 250mL of 100ppm phenol solution was studied under different temperatures subjected to 1.0L/min of ozone flow rate for total reaction time of 120 minutes. The catalytic ozonation of phenol under these different temperatures was measured against reaction time and their respective performance on the degradation of phenol, COD removal was observed.

Figure 8 presents the degradation and COD removal of phenol under different temperatures. It shows that the degradation phenol and removal of COD was decreased with increase in temperature and increases with increase in the reaction time.

Oguz *et al.*, [15], found that the dye removal efficiencies decreased from 80 to 52.5% while the COD removal was decreased from 54 to 35% when the temperature was increased from 18 to 70°C. The authors concluded that the decreased in the dye and COD removal efficiencies with increasing temperature were due to decreasing ozone solubility in solution with increasing temperature. A similar finding in the process of degradation oxalic acid had been measured [16].

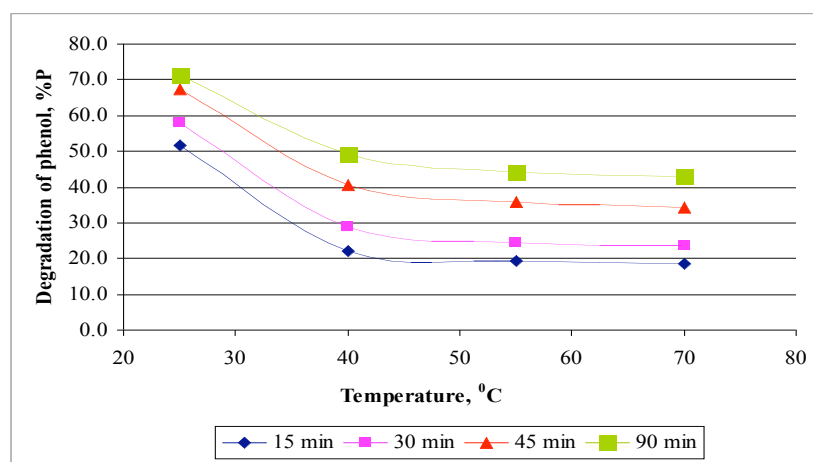


Figure 8 Degradation of phenol with Fe-ZB catalyst against temperature

3.7 Effect of Volume of Phenol

Figure 9 illustrates that, the effect of different volume of 100ppm phenol (i.e 300 and 500mL) which showed that degradation of phenol was decreased with increased in volume of phenol. The degradation of 500mL phenol solution was decreased from 81% for 300mL to 73.9% after 120 minutes. The degradation rate was similarly decreased from 0.57 to 0.52 per minute as a volume increase from 300 to 500mL.

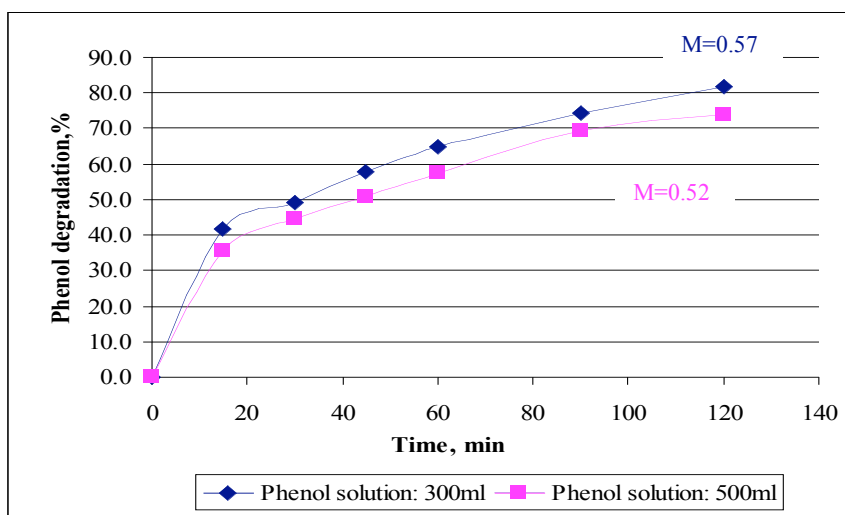


Figure 9 Effect of volume of phenol against reaction time

A similar pattern of the COD removal was observed where the COD removal of solution was decreased with volume of phenol to be treated. The percentage of COD removal was approximately 39.0 and 27.0 for 300 and 500mL of phenol solution, respectively after 30 minutes ozonation. At a longer reaction time (120 minutes), The COD removal was increases to 81.7 and 73.9% for 300 and 500mL of phenol solution, respectively.

4.0 CONCLUSIONS

Chemical oxidation with ozone is one of a technique use in wastewater treatment for the removal of organic pollutants. In some cases, ozone is use in combination with other agents to improve the degradation rate of organic pollutants. The degradation of phenol using a based and metal-based catalyst has been examined in this study.

It was observed that a smaller percentage of metal loading catalyst (Fe-ZB) showed a higher degradation compared to those with higher metal loading catalyst. It seemed that only a very small percentage of metal is required to obtain a substantial degradation of phenol in the study. Only a small amount of metal loading catalyst is warrant to initiate any radical chain reaction during degradation process, where the increased in percentage of metal in based catalyst would require a greater consumption of ozone to show any significant effect.

In general and as expected in the study, the ozonation flow rates and the reaction time play a major role in the degradation process. The degradation of phenol was higher at a higher ozone flowrate and longer reaction time as observed in most the experiments in this study. Similarly increase of pH and mass of catalyst increasing the rate of degradation. The rate of decomposition of ozone is increased at a higher pH containing a higher concentration of hydroxyl radical that leads to a higher degradation of phenol. In addition, increasing the mass of catalyst will provides more of the active side for the pollutant to react. On the contrary, the degradation of phenol decreases with increasing concentration, volume of phenol and temperature.

ACKNOWLEDGEMENT

This study had been supported by the IRPA research grant (Project no: 08-02-06-0004) and under the ministry of Science, Technology and Innovation (MOSTI), Malaysia.

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